

# Geotechnical Properties of Lunar Regolith and Effects on Lunar Surface Missions

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# Surface Activities

- Particle properties different from earth soils
- Moon environment different from terrestrial

Both impact the geotechnical properties and therefore the surface activities on the moon

# Particle Characteristics

## Earth

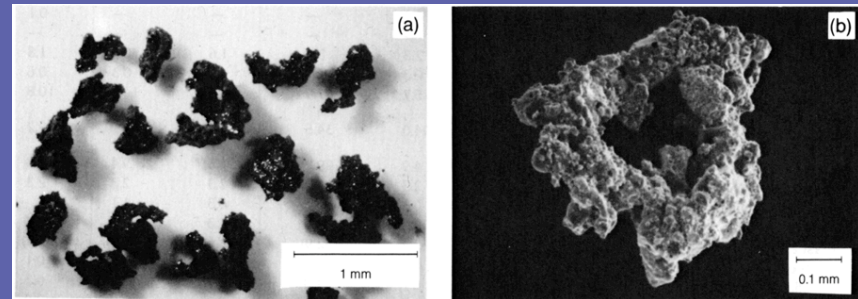
- Material affected by wind and water
  - High particle angularity not dominant
  - No agglutinates
  - Small particles typically clay mineralogy

## Moon

- Material affected by bombardment
  - Highly angular particles
  - Agglutinates
  - Many fine particles (dust)

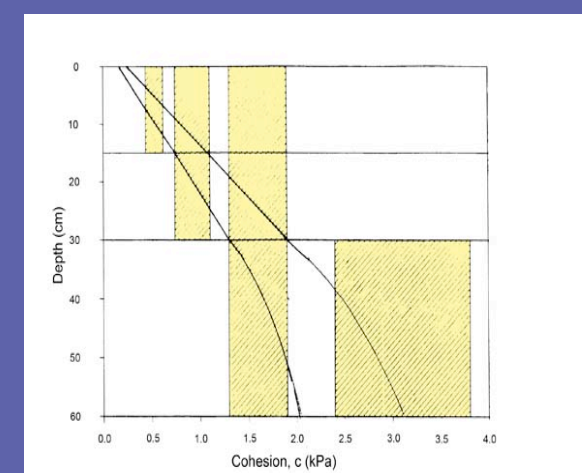
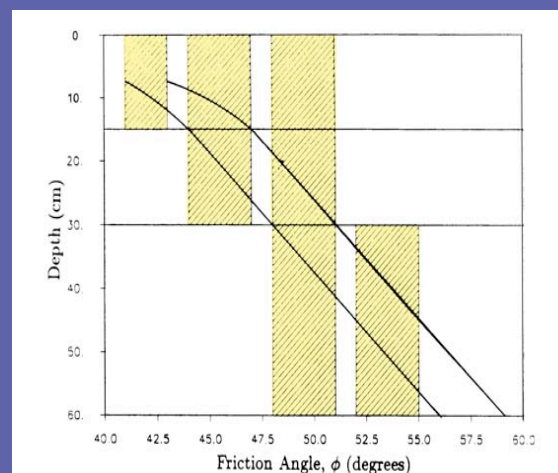
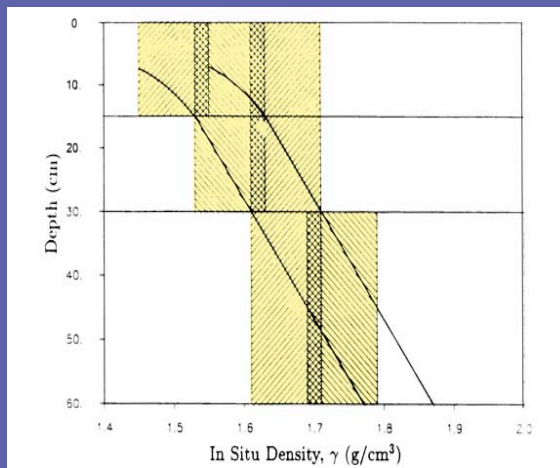
# Particle Shape

- Particles angular to subangular, reentrant, and elongated
  - Affects global behavior of the soil mass
- Elongation
  - Affects packing
  - Affects isotropy
  - Affects deformation
- Angularity
  - Affects packing
  - Affects deformation
- Alteration of environment
  - Sharp corners can get broken off with activity
  - Loosely bonded agglutinates can fracture
- Angular particles are abrasive



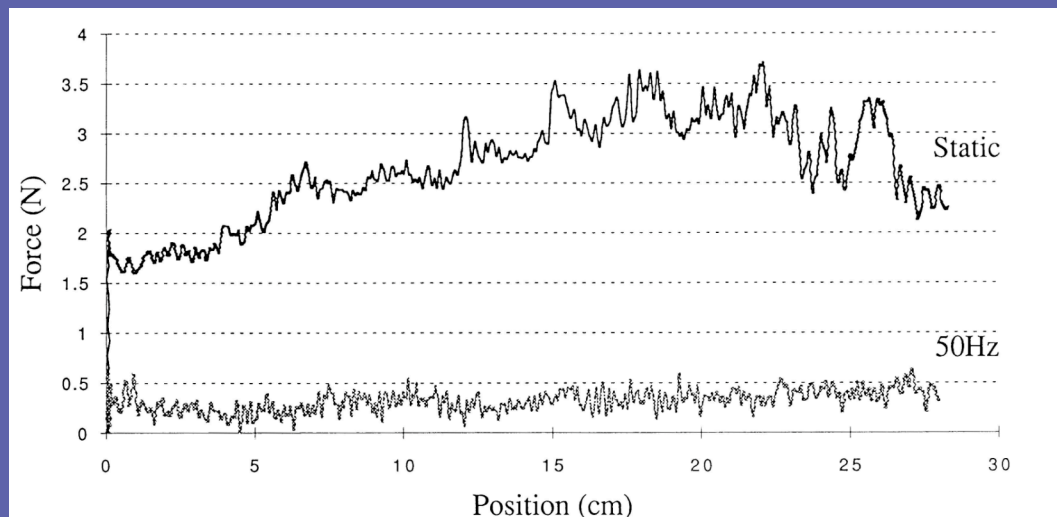
# Particle Shapes Drive Regolith Properties

- Upper portion of soil is relatively loose
  - Near crater rims, *very* loose soil present
  - Generally only to a small depth
  - Due to the low density, dust is lifted with activity
  - May need to prepare surface for scientific instruments
  - Mobility will require special attention, particularly heavy transport
    - Wheel size scaling an issue - large diameter wheels needed



# Particle Shapes Drive Regolith Properties

- While loose on the surface, lunar regolith quickly gains density with depth
  - Results in a very strong subgrade that can be difficult to penetrate
    - Encourages more shallow excavation over larger area
  - Requires more energy or more efficient use of energy to excavate
    - Vibration of tools at natural frequency of soil-tool system can reduce draft force 50-90%
  - More resistance on cutting blades will cause more wear
    - As blades wear, blade material will go into the regolith



# Comparison of Properties

	Terrestrial Soils (Dry, cohesionless)	Lunar Regolith
Friction Angle $\phi$ , degrees	30-38	44-56
Cohesion/Adhesion $c$ , kN/m <sup>2</sup>	0	0.05-1.50
Specific Mass of Solids, $\rho_s$ , g/cm <sup>3</sup>	2.7	3.1
Unit Weight $\gamma$ , kN/m <sup>3</sup>	14-19	2.9-3.6 for 1/6g
Bearing Capacity of a 0.10 m by 0.10 m footing on level ground $q_f$ , kPa ( <i>controlling term: <math>e^{\pi \tan \phi}</math></i> )	8-45	27-1840
Allowable bearing capacity	15 psi	2 kPa/cm*d <sub>acc</sub> 0.2 psi rec.

Material properties can be used to advantage, or can be a challenge

# Environmental Factors

## Earth

- Air

- Air pressure increases can reduce forces on soil

- Water

- Optimize compaction effort
  - Keeps dust & electrostatic forces down

- Gravity 1 g

- Higher stress levels, electrostatics & other small forces take a back seat

## Moon

- Vacuum

- Will affect flow of material

- Dry

- Electrostatics larger factor in cohesion
  - Alternate dust mitigation required

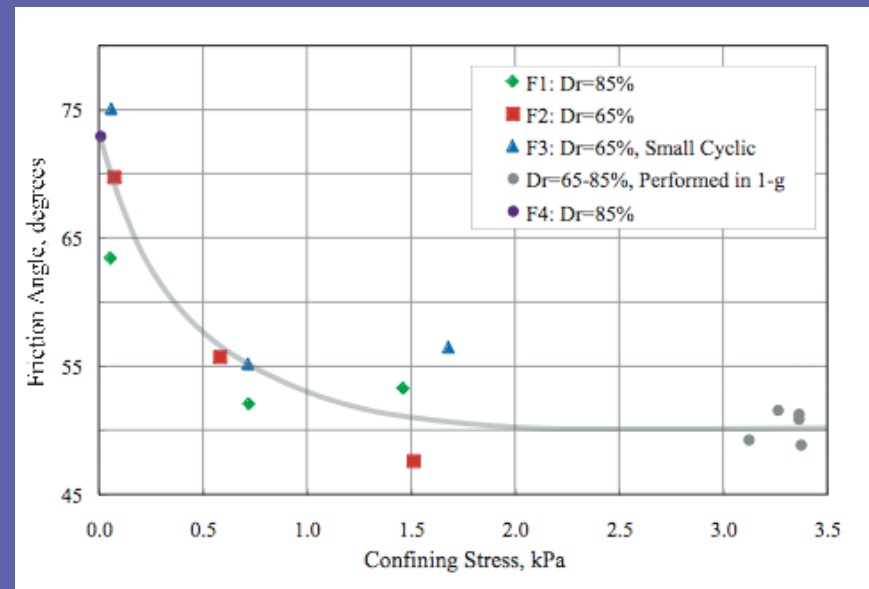
- Gravity 1/6 g

- Low self-weight decreases stress levels, electrostatics & other small forces important



# Particle Interaction in Dry, Low Stress Environment

- When self-weight influence decreased, other factors show larger contribution to behavior
  - Interlocking
  - Electrostatics
  - Impurities
  - Van der waals forces



# Science & Engineering

- Interparticle forces are crucial to engineering
- Engineers need to understand dust charging
  - Consider its effects on geotechnical behavior
  - Soil strength and deformation behavior
  - Soil transport and processing (ISRU)
  - Optics
  - Mechanisms
  - Human health safety
- Dust also of interest to scientists
  - What scientists learn will help engineers
  - e.g. When studying the levitation and transport of charged dust particles, what charges are on the particles?

# Conclusion

- Environment on the moon has affected and will continue to affect properties of regolith
- Properties of the regolith (deformation, abrasiveness, dust) affect all surface activities

Understanding of basic engineering properties of the surface are vital for reducing risks of science & other facilities on the moon